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(54) LIQUID FLOW STRAIGHTENING DEVICE

(71) We, TOKICO, LTD., of No. 6—3, 1-Chome, Fujimi, Kawasaki-Ku, Kawasaki-City, Kanagawa-Ken, Japan, a Japanese Corporation, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates generally to a liquid flow straightening device or straightener for controlling the flow of liquid to form a substantially uniform flow having a predetermined velocity distribution. More particularly, the invention relates to a device to be provided up-stream from a flowmeter installed in a liquid pipeline and operating to rectify the liquid flow into a uniform flow with a cross-sectional velocity distribution curve that does not show a reversal of curvature.

In general, the flow of a liquid flowing in a pipeline is not uniform but contains irregularities and turbulence such as turning or twisting flow, flow with irregular velocity distribution, pulsating flow, and eddies and vortexes. When the flowrate or flow quantity of a liquid having such flow characteristics is measured directly as it is by a flow meter of indirect or inferential type such as a turbine flow meter, an electromagnetic flow meter, a vortex flow meter, or a differential pressure flow meter, the precision of measurement drops greatly, and accurate and positive measurement of flow cannot be carried out.

For this reason, use is made of a flow straightening device intended to rectify irregular liquid flows as described above. Among the flow straightening devices of this character known heretofore, there have been devices of the type comprising a main structure in the form of a hollow cylinder and plurality of relatively thin tubes of the same diameter and the same length arranged in parallel and fixed as a bundle within the main cylindrical structure and aligned in the axial direction thereof and devices of the type comprising a main hollow cylindrical structure and a plurality of guide plates assembled in the form of a grating within the main structure thereby to divide the space within the main structure into a plurality of parallel prismatic spaces having square cross sections and alined in the axial direction of the main structure.

By the use of a conventional flow straightener as described above, rotating or twisting flow constituting one component of irregular flow of a liquid can be effectively straightened, but irregularities in the flow velocity distribution in the cross-sectional direction of the pipe conducting the liquid cannot be rectified.

In the case where there is no rotating flow in the liquid flow, the liquid flow velocity distribution assumes a specific configuration such that maximum velocity is attained at the axial centerline of the pipe, and from this maximum value the velocity decreases toward the wall of the pipe, the distribution curve from centerline to wall being a continuous smooth curve that does not show a reversal of curvature. However, in the case where there is a rotating flow in the liquid flow about the axial centerline of the pipeline, the liquid flow exhibits a velocity distribution wherein there is a slight reduction in the velocity at the axial centerline and regions in the neighbourhood thereof. This rotating flow is unavoidably produced when the liquid flow passes through a strainer or an elbow part of the pipeline.

Study of this phenomenon, with the aim of determining the cause of this irregularity in the velocity distribution in the case where a rotating flow has led to the following conclusion. A liquid flowing with a rotating flow through a pipeline flows therealong as it rotates about the axis of the pipeline. For this reason, the liquid is subjected to centrifugal force, which is countered by centripetal force exerted by the pipe wall, and thereby assumes a liquid pressure distribution wherein the pressure at the pipeline axis is relatively low and in the vicinity of the pipeline wall is relatively high. As a result,

the flow velocity at the pipeline centerline, where the liquid pressure is low, becomes less than the flow velocity in the vicinity of the pipeline wall, where the liquid pressure is high. For this reason, the liquid velocity distribution curve develops a reversal of curvature, that is, a concavity, at the pipeline centerline and in the neighbourhood thereof as mentioned above.

Since a conventional flow straightener as briefly described above has a construction wherein a main cylindrical structure is merely subdivided into spaces of the same cross sectional area and the same length, a liquid flowing through this device is merely straightened with respect to only its rotating flow, but its nonuniform velocity distribution passes uncorrected through the device.

It is a general object of the present invention, which is based on the above stated conclusion, to provide a novel and useful liquid flow straightening device in which the above described difficulty accompanying known flow straighteners has been overcome.

A specific object of the invention is to provide a liquid flow straightening device capable of accomplishing effective flow straightening whereby rotating flow is eliminated, and, at the same time, irregular flow velocity distribution arising from the rotating flow is corrected and rendered regular.

Another object of the invention is to provide a liquid flow straightening device adapted to have a cross-sectional distribution of resistance to the liquid flow such that the resistance at the axial centerline of the pipeline and in the vicinity thereof is relatively low thereby to correct the irregular velocity distribution wherein there is a portion of low flow velocity at the centerline and in the vicinity thereof as described above.

Other objects and further features of the invention will be apparent ffom the following detailed description with respect to preferred embodiments of the invention when read in conjunction with the accompanying drawings.

In the drawings:

FIGS. 1A and 1B are side view diagrams respectively indicating the cross-sectional distribution of liquid flow velocity without and with flow straightening by the flow straightening device of the invention;

FIGS. 2A and 2B are respectively a front view and a cross-sectional side view, showing the essential construction of a first embodiment of a flow straightening device of the invention;

FIGS. 3A and 3B are respectively a front view and a cross-sectional side view, showing the essential construction of a second embodiment of a flow straightening device of the invention;

FIGS. 4A and 4B are respectively a front view and a cross-sectional side view, showing the essential construction of a third embodiment of a flow straightening device of the invention;

FIGS. 5A and 5B are respectively a front view and a cross-sectional side view, showing the essential construction of a fourth embodiment of a flow straightening device of the invention;

FIGS. 6A and 6B are respectively a front view and a cross-sectional side view, showing the essential construction of a fifth embodiment of a flow straightening device of the invention; and

FIGS. 7A and 7B are respectively a front view and a cross-sectional side view, showing the essential construction of a sixth embodiment of a flow straightening device of the invention.

In general, the velocity distribution of a liquid flow in a pipeline accompanied by a rotational flow is as indicated in FIG. 1A and as described hereinabove. Here the length of the arrows represent the magnitude of the flow velocity. As is indicated by this representation, the flow velocity at the axial centerline, as indicated by the single-dot chain line, of a pipeline 10 and in the vicinity thereof is relatively low and similarly in the vicinity of the pipe wall, while the flow velocity in the region intermediate between the centerline and the wall is comparatively high. Consequently, a concavity is formed in the velocity distribution curve in the region thereof near the centerline.

Accordingly, in accordance with the present invention, the flow rectifying device is so adapted that its resistance to the liquid flow at, and in the vicinity of, the central part thereof is caused to be relatively low, and by passing a liquid having an irregular flow velocity distribution as indicated in FIG. 1A through the flow straightening device of the present invention, a uniform velocity distribution wherein, as indicated in FIG. 1B, the maximum velocity occurs at the centerline of the pipeline 10, and the velocity decreases progressively toward the pipe wall in accordance with a smooth distribution curve that does not show a reversal of curvature, is obtained.

In the first embodiment of the flow rectifying device according to the invention as illustrated in FIGS. 2A and 2B, the flow straightening device 20 is installed between a strainer (not shown) in a liquid flow-path pipe and a flow meter (not shown). This flow straightening device has a hollow cylindrical main structure 21 having an inner diameter which is substantially the same as that of the liquid flow-path pipe. Within this cylindrical main structure 21, there is fixedly installed a tube group 22 for flow straightening

comprising a plurality of thin-wall tubes of the same length but different diameters alined parallel to the axis of the main structure 21, thereby forming a matrix of through passageways parallel to the centerline of the main structure.

This tube group 22 for flow straightening comprises a tube 23 of relatively large diameter disposed with its axis coincident with the axis of the cylindrical main structure 21, a plurality of medium-diameter tubes 24 disposed parallel to and around the central tube 23, and a plurality of relatively smaller diameter tubes 25 disposed parallel to and around the tubes 24 and, moreover, between the tubes 24 and the inner wall surface of thc main structure 21.

By this arrangement of the flow straightening device 20, the tube 23 at the center of the main structure 21 has the largest diameter and thus the largest cross-sectional area, and the tubes 24 in the neighborhood thereof have diameters which are next in size. For this reason, the resistance due to skin friction to the flow of the liquid through the device 20 is of minimum value at the central part of the main structure 21 and increases progressively toward the pipe wall.

Accordingly, when a liquid flow accompanied by a rotating flow and having an irregular velocity distribution as indicated in FIG. 1A passes through the flow straightening device of the invention, the resistance to flow which the liquid encounters at the centerline and in the vicinity thereof of the main structure 21 is relatively less than that at other parts. As a result, the concavity in the central part of the velocity distribution curve as shown in FIG. 1A is eliminated. Therefore, the resultant velocity distribution curve as a whole has a smooth regular shape of a typical uniform flow, as indicated in FIG. 1B, in which the velocity is at a maximum at the central part.

Furthermore, the flow straightening device of the invention functions in the same manner and with equal effectiveness as a conventional flow straightener to straighten any rotational flow in a liquid flow.

In the second embodiment of the flow straightening device of the invention as illustrated in FIGS. 3A and 3B, the device 30 comprises a hollow cylindrical main structure 31 and a group 32 of a plurality of flow straightening plates of the same length assembled within the main structure 31 as described below to form a grating pattern as viewed in a front view. This plate group 32 comprises a plurality of parallel, spaced-apart vertical plates 33 extending vertically from wall to wall of the main structure 31 and a plurality of parallel, spaced-apart horizontal plates 34 extending horizontally from wall to wall of the main structure 31. These vertical and horizontal plates, in combination, form a plurality of through passageways parallel to the centerline of the main structure 31.

The spacing between adjacent vertical plates 33 and the spacing between adjacent horizontal plates 34 are large at and in the vicinity of the centerline of the main structure 31 and progressively decrease toward the wall of the main structure 31. Accordingly, the cross-sectional areas of the plurality of lontitudinally extending spaces of square cross section formed by the mutually intersecting vertical plates 33 and horizontal plates 34 are relatively large in the neighborhood of the centerline of the main structure 31 and progressively decreases toward the pipe wall.

The functional effectiveness of the device of the instant embodiment is similar to that of the device of the first embodiment and, therefore, will not be described again.

In the third embodiment of the flow straightening device according to the invention as illustrated in FIGS. 4A and 4B, the device 40 comprises a hollow cylindrical main structure 41 and a tube group 42 for flow straightening made up of a plurality of thin-wall tubes of the same inner diameter installed in a bundle in longitudinal alinement with the centerline of the main structure 41.

The flow straightening tube group 42, as an integral structure, has conical concave or inwardly dished ends, the surface of each defining the ends of all individual tubes. The concavity thus formed at each end thereby has a concave bowl shape with the deepest part at the centerline part of the tube group 42. Accordingly, the tubes of this tube group 42 increase progressively in length from a minimum at the certerline of the main structure 41 to a maximum at the wall thereof.

For this reason, the frictional resistance to the flow of a liquid passing through this flow straightening device 40 is a minimum at the centerline of the main structure and increases progressively toward the pipe wall.

Therefore, by the use of the flow straightening device of the instant third embodiment, it is possible to rectify a liquid flow accompanied by a rotational flow and having a velocity distribution as indicated in FIG. 1A into a liquid flow not accompanied by a rotational flow and having a velocity distribution as indicated in FIG. 1B, in a manner similar to that of the aforedescribed first embodiment.

In the fourth embodiment of the flow straightening device according to the invention as illustrated in FIGS. 5A and 5B, the device 50 comprises a hollow cylindrical main structure 51 and a straightening plate group 52 made up of a plurality of vertical

plates 53 and horizontal plates 54 installed at right angles to each other within the main structure 51 and extending from wall to wall of the main structure 51. The vertical plates are disposed at equal spacing intervals as are the horizontal plates.

The flow straightening plate group, as an integral structure, has conical concave or inwardly dished ends, the surface of each defining the ends of all individual plates in a manner similar to that of the preceding embodiment. The concavity thus formed at each end thereby has a concave bowl shape with the deepest part at the centerline part of the plate group 52. Accordingly, the lengths of the plurality of prismatic spaces of square cross section extending in the flow direction and formed by the mutually intersecting vertical plates 53 and horizontal plates 54 increase progressively from a minimum at the centerline of the main structure 51 to a maximum at the wall thereof.

The functional effectiveness of the flow straightening device of the instant embodiment is similar to that of the device of the preceding third embodiment and, therefore, will not be described again.

While, in the above described third and fourth embodiments, both the tube group 42 for flow straightening and the flow straightening plate group 52 have end surfaces of conical concave or bowl shape, only one end surface of each group may be so formed in the shape of a bowl, and the other end surface may be in the form of a plane perpendicular to the centerline of the main structure. Examples of numerical values of a specific example of practice which is formed in this manner are: an inner diameter of the main structure of 4 inches; total length thereof 400mm.; and a depth of the bowl-like concavity of 100mm. The applicant has found that these relative dimensions afford optimum flow straightening effectiveness.

In a fifth embodiment of the flow straightening device of the invention as illustrated in FIGS. 6A and 6B, the device 60 comprises a hollow cylindrical main structure 61 and a tube group 62 for flow straightening made up of a plurality of thin-wall tubes installed as a bundle in the main structure 61 in alinement with the centerline thereof. The tube group 62 comprises a central tube 63 of relatively large diameter disposed at the central part of the main structure coaxially therewith, a plurality of medium-diameter tubes 64 disposed parallel to and around the central tube 63, and a plurality of tubes 65 of relatively small diameter disposed parallel to the tubes 63 and 64 and between the tubes 64 and the inner wall surface of the main structure 61. In addition, the flow straightening tube group 62 has at each end thereof a concave surface having the shape of a bowl whose deepest part is at the central part of the main structure 61.

The fifth embodiment corresponds to a combination of the different diameter tubes of the first embodiment with the different length tubes of the third embodiment. Accordingly, it will be apparent from the foregoing description of these preceding embodiments that the resistance to the flow of a liquid flowing through the flow straightening device 60 is a minimum at the centerline of the main structure 61 and progressively increases outwardly toward the wall of the main structure, the functional effects of the first and third embodiments, that is, the effects of the difference in diameter of the tubes and the difference in length of the tubes from the centerline to the wall, being combined.

In the sixth embodiment of the flow straightening device according to the invention as illustrated in FIGS. 7A and 7B, the device 70 comprises a hollow cylindrical main structure 71 and a flow straightening plate group 72 made up of a plurality of vertical and horizontal plates 73 and 74 installed perpendicularly to each other within the main structure 71 in a manner similar to that of the aforedescribed second embodiment shown in FIGS. 3A and 3B.

The spacing between the vertical plates 73 and the spacing between the horizontal plates 74 are at a maximum at and in the vicinity of the centerline of the main structure 71 and progresisively decrease outward therefrom toward the wall of the main structure. Accordingly the cross-sectional areas of the plurality of prismatic spaces of square cross section formed by the perpendicularly intersecting vertical plates 73 and horizontal plates 74 are relatively large at and in the vicinity of the centerline of the main structure 71 and progressively decrease outward toward the wall of the main structure. In addition, each end of the plate group 72 is in the form of a concave surface of bowl shape with the deepest part at the central part of the main structure.

Thus, the instant sixth embodiment corresponds to a combination of the differently spaced plates of the second with the different length plates of the fourth embodiment described hereinbefore and illustrated respectively in FIGS. 3A and 3B and FIGS. 5A and 5B. As is apparent from the previous description of these preceding embodiments, the resistance to the flow of a liquid flowing through this flow straightening device 70 is a minimum at the centerline part of the main structure 71 and progressively increases outward therefrom toward the wall of the main structure. Accordingly, flow straightening is effectively accomplished through the combined

functional effects of the varying cross-sectional areas and the varying lengths of the above mentioned prismatic through spaces formed between the vertical and horizontal plates.

While, in the above described fifth and sixth embodiments, both the tube group 62 and the plate group 72 have bowl-shaped concavities at their two ends, they may be provided with a bowl-shaped concavity at only one end, the other end being a planar surface.

Furthermore, while the bowl-shaped concavities at the ends of the tube groups and the plate groups in the above described third through sixth embodiments are shown in FIGS. 4B through 7B as being of substantially conical shape defined by straight generatrices extending from the wall of the main structure of the device toward the centerline thereof, the surfaces of these concavities may be of a curved shape coresponding to the curved surface of the concavity at the central part of the velocity distribution curve shown in FIG. 1A.

In actual practice, however, it is difficult to fabricate the concavities with a curved surface as mentioned above, and, furthermore, the shape of the curved surface cannot be readily determined because of various influencing factors such as the character of the pipeline, and the flow velocity. For this reason, the concavities can be made substantially conical with straight generatices as long as the indented part at the center of the velocity distribution curve shown in FIG. 1A is corrected. In this case, by installing the flow straightening device in a straight pipe upstream from a flow meter at a distance of the order of 15D (where D is the flow inlet diameter of the flow meter), for example, upstream from the flow meter, a liquid flow through the flow straightening device is rectified in the straight pipe part from the device to the flowmeter by the effect of frictional resistance to the flow, whereby the flow velocity is gradually caused to assume the regular distribution shown in FIG. 1B and thus flows into the flow meter.

Furthermore, since there is no special need to vary the frictional resistance of the pipe in the vicinity of the pipe wall, the end surfaces of the flow straightening tube group or plate group forming the through passageways need not be concave throughout their extent, but may for example comprise an annular planar outer portion perpendicular to the pipe centerline and extending radially inward from the pipe wall through a distance of the order of 1/5, for example, of the pipe diameter, and an inner bowl-shaped portion.

WHAT WE CLAIM IS:—

1. A liquid flow straightening device comprising a hollow cylindrical main structure to be connected in a pipeline forming a liquid flow path and a flow straightening member provided within said main structure and comprising walls dividing the space within the main structure into a plurality of through passageways parallel to the longitudinal centerline of the main structure, said flow straightening member being so adapted that the frictional resistance due to skin friction of said walls of said passageways to a liquid flowing through the passageways at and in the vicinity of the centerline of the main structure is less than the frictional resistance due to skin friction of said walls of other passageways at other parts, the said frictional resistance increasing progressively with increasing distance from the centerline.

2. A liquid flow straightening device as claimed in claim 1 in which said flow straightening member comprises a group of a plurality of tubes disposed parallel to said centerline within the main structure, tubes of said group at or in the vicinity of the centerline being of a greater diameter than other tubes at other parts, and the tube diameters decreasing progressively with increasing distance from the centerline.

3. A liquid flow straightening device as claimed in claim 1 in which said flow straightening member comprises a group of a plurality of flow straightening plates assembled within the main structure parallel to the centerline thereof and in a manner to intersect perpendicularly thereby to form passageways of substantially square cross section, the cross sectional areas of said passageways at and in the vicinity of the centerline being greater than those of other passageways at other parts and the cross-sectional areas of the passageways decreasing progressively with increasing distance from the centerline.

4. A liquid flow straightening device as claimed in claim 1 in which said flow straightening member comprises a group of a plurality of tubes assembled within the main structure parallel to the centerline thereof, and at least one end of said group of tubes, as an integral structure, has a surface formed by the ends of the tubes in the shape of a bowl-like concavity with its deepest part at the centerline, whereby the lengths of the tubes at or in the vicinity of the centerline are shorter than the lengths of other tubes at all other parts, the tube length increasing progressively with increasing distance from the centerline.

5. A liquid flow straightening device as claimed in claim 1 in which said flow straightening member comprises a flow straightening group comprises a first group of a plurality of flow straightening plates disposed within the main structure parallel

to the centerline thereof and with equal spacing and a second group of a plurality of flow straightening plates disposed perpendicularly to the flow straightening plates of the first plate group and parallel to each other with equal spacing, and at least one end of said flow straightening member, as an integral structure, has a surface formed by the ends of the plates in the shape of a bowl-like concavity with the deepest part at the centerline, whereby the lengths of said passageways at or in the vicinity of the centerline are shorter than the lengths of other passageways at all other parts, the lengths of said passageways increasing progressively with increasing distance from the centerline.

6. A liquid flow straightening device as claimed in claim 2 in which at least one end of said group of tubes, as an integral structure, has a surface formed by the ends of the tubes in the shape of a bowl-like concavity with the deepest part at the centerline, whereby the lengths of the tubes at or in the vicinity of the centerline are shorter than the lengths of other tubes at all other parts, the tube lengths increasing progressively with increasing distance from the centerline.

7. A liquid flow straightening device as claimed in claim 3 in which at least one end of said group of flow straightening plates, as an integral structure, has a surface formed by the ends of the plates in the shape of a bowl-like concavity with the deepest part at the centerline, whereby the lengths of said honeycomb passageways at or in the vicinity of the centerline are shorter than the lengths of other passageways at all other parts, the lengths of said passageways increasing progressively with increasing distance from the centerline.

8. A liquid flow straightening device substantially as described with reference to FIGS. 2A and 2B, 3A and 3B, 4A and 4B, 5A and 5B, 6A and 6B or 7A and 7B of the accompanying drawings.

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FIG. 1A

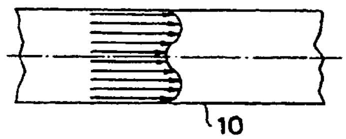

FIG. 1B

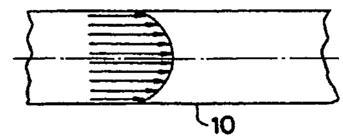

FIG. 2A

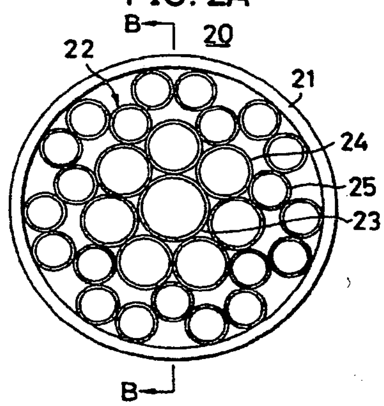

FIG. 2B

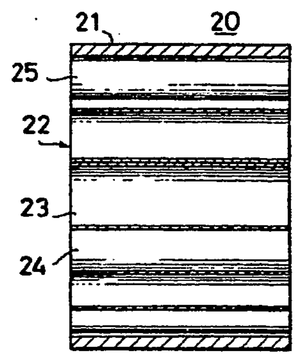

FIG. 3A

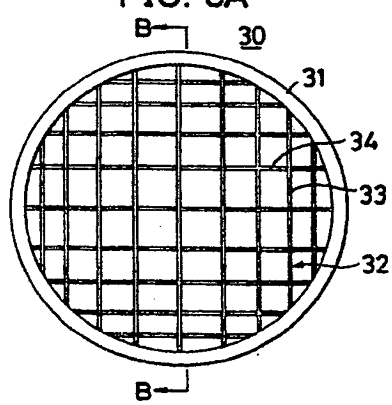

FIG. 3B

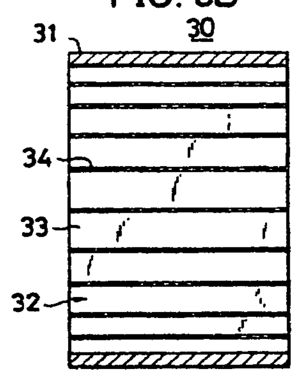

FIG. 4A

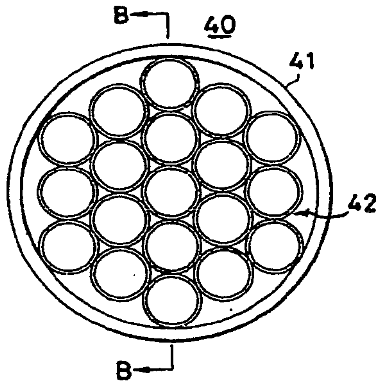

FIG. 4B

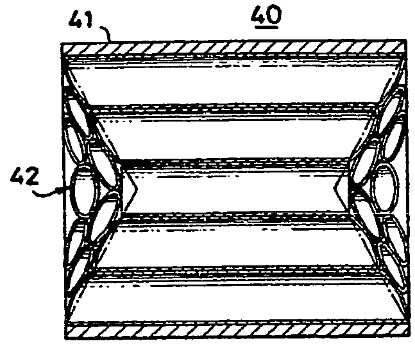

FIG. 5A

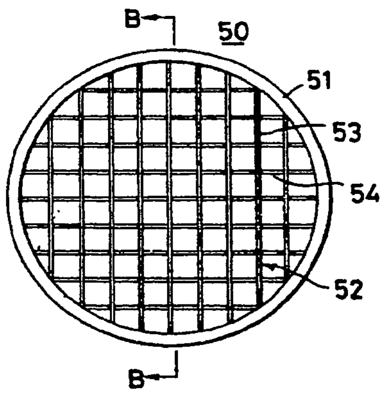

FIG. 5B

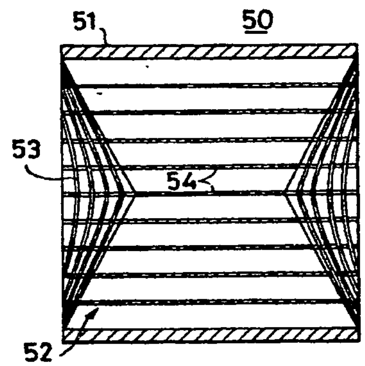

FIG. 6A

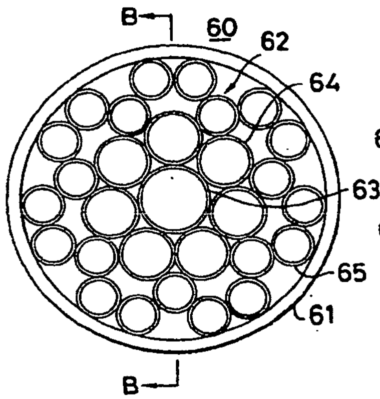

FIG. 6B

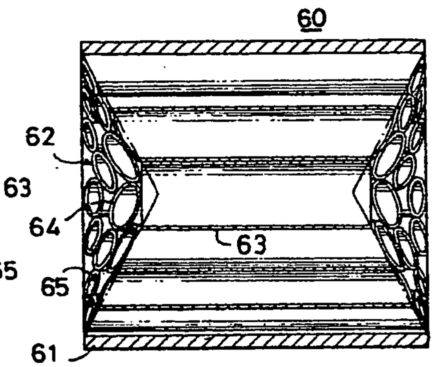

FIG. 7A

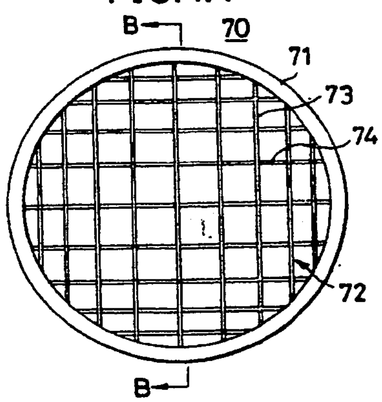

FIG. 7B